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VISION WITH THE AN/PVS-5 NIGHT VISION GOGGLES

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This paper presents the results from a series of experiments in which visual performance using the AN/PVS-5 night vision goggle was measured. Modulation transfer functions of the man-goggle system were determined and compared to results obtained with unaided viewing. It was found that the man-goggle system performance was superior to unaided visual performance at average target luminances equivalent to 5% and 25% moon illuminances. At a target luminance equivalent to a full moon illuminance, unaided visual performance was superior

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at higher spatial frequencies, while remaining poorer at the lower spatial frequencies. Using a modified Howard-Dolman apparatus, it was determined that the stereoscopic threshold was degraded with the man-goggle system. Field measurements of relative depth discrimination using all available visual cues showed that performance of the man-goggle system was statistically equivalent to unaided photopic visual performance at intermediate viewing distances, but was inferior to unaided viewing at distances of 500 feet or greater. While the night vision goggle reduces the ambient light level necessary for military rotary wing support, use of the goggle does not allow the operator to perform with photopic visual efficiency.

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This paper presents the results from a series of experiments in which visual performance using the AN/PVS-5 night vision goggle was measured. Modulation transfer functions of the man-goggle system were determined and compared to results obtained with unaided viewing. It was found that the man-goggle system performance was superior to unaided visual performance at average target luminances equivalent to 5% and 25% moon illuminances. At a target luminance equivalent to a full moon illuminance, unaided visual performance was superior at higher spatial frequencies, while remaining poorer at the lower spatial frequencies. Using a modified Howard-Dolman apparatus, it was determined that the stereoscopic threshold was degraded with the man-goggle system. Field measurements of relative depth discrimination using all available visual cues showed that performance of the man-goggle system was statistically equivalent to unaided photopic visual performance at intermediate viewing distances, but was inferior to unaided viewing at distances of 500 feet or greater. While the night vision goggle reduces the ambient light level necessary for military rotary wing support, use of the goggle does not allow the operator to perform with photopic visual efficiency.

INTRODUCTION

Recent military experiences and modern tactical considerations have dictated the requirement for placing emphasis on sustained operations with future military deployment. Such sustained operations imply continuous activity by military units during periods of darkness as well as daylight. The requirement for operating during periods of reduced illumination will place new perceptual demands and physiological stress upon the individual soldier. Since vision is the principal sensory modality with which

man gathers information from the external world about him in order to function effectively, major military operations historically have been conducted during periods of good illumination.

The eye and related neural structures comprise an extremely effective information processing system. The visual system has a total dynamic range in response to light stimulation much greater than any other known photodetection system. In order to achieve this large dynamic range, several physiological adaptations and compromises have been accomplished. The duplicity arrangement of the retina represents one of the most effective adaptations. At moderate to high light levels, the cone or photopic system is operational and processes visual information with remarkable resolution along several dimensions (color, spatial, temporal). At lower light levels, down to the order of several photons, the rod or scotopic system is operational. In order to be capable of functioning at low light levels, some severe visual compromises have been made. For example, the scotopic system integrates light over relatively large retinal areas so spatial resolution is considerably reduced. No color information is processed, and temporal processing is reduced. The limited information provided by the scotopic visual system restricts the capability of the soldier to effectively perform his military duty.

In recognition of the requirement for sustained military operations, two avenues have been pursued to reduce the impact of the basic limitations of the scotopic visual system on military operations during periods of darkness. The first approach has been to increase the amount of time devoted to operational training at night. It is felt that this will reduce the stress and increase the perceptual proficiency of individuals during night military operations. However, the anatomy and physiology of the human visual system are relatively immutable and certain tasks, such as nap-of-the-earth (NOE) rotary wing flight, require more visual information than the scotopic system can provide. To fulfill this need for low light level visual information, major technological advances in light amplification and infra-red systems have been developed in recent years.

The AN/PVS-5 Night Vision Goggle (NVG), developed by the U.S. Army Night Vision Laboratory, is considered an effective interim solution to allow U.S. Army aviators to conduct rotary wing operations at night. While the NVG

performs admirably in light amplification, use of the NVG has presented new problems and questions for those of us concerned with the human in this man-machine loop. For the past several years, personnel at the U.S. Army Aeromedical Research Laboratory have been conducting experiments designed to determine the present and potential impact of the NVG on aviators during rotary wing flight. A previous AGARD Conference report[1] reviewed studies conducted by other laboratories on the NVG and these will not be further detailed here. However, several reports have more immediate pertinence to the present conference and should be discussed briefly.

As with any new device, there has been some concern about possible damage to the eyes while using the NVG. Several military agencies reported that their personnel were complaining of a so-called "brown eye syndrome" after using the NVG. This problem was investigated and found to be simply a color afterimage which should be expected after viewing the narrowband output of the P20 phosphor used in the goggle[2]. In addition, the persistence of the afterimage lasted only a brief period of time. However, the P20 phosphor output has caused another problem of some significance. This is the loss of color information while using the NVG. Because of the reduced resolution and narrowband output of the goggle, standard navigation maps cannot be used. Recently, the U.S. Defense Mapping Agency has developed an experimental map consisting of a reversed contrast display. It has been determined that adequate information can be obtained from these black background maps using either the goggle or with the naked eye and aviation red illumination[3].

The NVG is powered by a 2.7 volts wafer battery. Since goggle failure occurs due to low battery output without prior warning, it is of some importance to know the state of adaptation of the eye upon removal of the NVG. With normal viewing conditions, luminance output of the goggle display is between 0.7 foot lambert and 1.5 foot lamberts. It was found[4] after allowing subjects to fully dark adapt followed by a 5-minute period of viewing with the goggle that visual sensitivity had degraded to that level normally found at approximately 10 minutes into the course of dark adaptation. However, the average recovery time (i.e. time to return to 30 minute level of sensitity) was 2 minutes.

This report presents results from experiments designed to determine the effects of the goggle on a user's ability to make relative depth discriminations under both field and laboratory conditions. Data are also presented on the modulation tranfer function of the man-goggle system.

METHODS and RESULTS

(1) Laboratory Measures of Relative Depth Discrimination

A modified Howard-Dolman apparatus was used for the laboratory measures of relative depth discrimination. Modifications to the basic instrument consisted of driving the variable vertical rod by a motor which was controlled by a radiofrequency receiver. The observers held a radiofrequency transmitter and moved a toggle switch in a fore and aft direction to elicit rod movement and effect alignment with the fixed comparison rod. When an observer indicated alignment of the two rods, displacement readings to the nearest 0.1 mm were taken with a digital voltmeter which read the voltage across a linear potentiometer attached to the variable rod. Except for a 0.75° X 1.75° viewing window in the front of the instrument, the apparatus was completely enclosed and illuminated with electroluminescent panels lining the sides and top of the case. The iuminance levels used were 6.70 foot lamberts for the naked eye observations and 0.012 foot lambert for the observations using the NVG.

Six experienced aviators were used as observers. A modified method of adjustment was used and during each testing period, an observer would make 10 readings under each of four different viewing conditions: unaided monocular, unaided binocular, monocular with NVG, binocular with NVG. To eliminate an order effect, the viewing conditions were alternated after each observation. All observations were made at a viewing distance of 6 meters from the fixed rod.

Hirsch and Weymouth[5] first discussed the theoretical implications of measures of depth discrimination thresholds, and their suggestion of using the standard deviation of the linear displacement scores has been adopted by other investigators in subsequent reports. Accordingly, our threshold measure was the standard deviation of the displacement scores from the 10 observations made by each observer under the different viewing conditions. Table 1 shows the average

threshold obtained from the six observers with the four viewing conditions. It can be seen in this table

Table 1. Relative Depth Threshold with Howard-Dolman Apparatus

	Linear Threshold (Centimeters)	Angular Threshold (Seconds of Arc)
Binocular	1.34	5.0
Monocular	5.19	19.3
Binocular/NVG	4.80	17.9
Monocular/NVG	7.04	26.2

that unaided binocular viewing yielded results superior to any of the remaining three conditions. Binocular viewing with the NVG was slightly better than unaided monocular viewing, while monocular viewing with the NVG gave the poorest results. Scheffe's S multiple comparison method was used to statistically evaluate these data. There was a significant difference ($p<.01$) between the results obtained with unaided binocular viewing and those found with the other three viewing conditions. However, no statistically significant difference ($p<.01$) was indicated between the thresholds with unaided monocular viewing, binocular-NVG viewing, and monocular-NVG viewing.

Thresholds in terms of angular disparities are also shown in Table 1. These were determined using the following equation[5]:

$$\eta = \frac{a\,(\Delta d)}{d^2} \cdot 206{,}280$$

where

η = angular threshold in seconds of arc

a = interpupillary distance

Δd = linear displacement of the variable rod from the fixed rod

d = observation distance

A binocular threshold of approximately 5 seconds of arc is of the same order of magnitude as those which have been presented in previous investigations[5,6].

(2) Field Measures of Relative Depth Discrimination.

The six observers used in the laboratory study were also used for the field measures of relative depth discrimination. Again, a modified method of adjustment was used and the observer's task was to indicate when two targets, one fixed and one variable, were judged to be at the same distance from him. However, several procedural changes were made. Only three viewing conditions were used: monocular viewing during the day, binocular viewing during the day, binocular viewing with the NVG at night. Only one viewing condition was tested during each observation period, and two aviators, alternately responding, were tested during the same period. Full moon, no overcast conditions prevailed during the night testing periods with photometric measures of moon illuminance averaging 1.7 x 10^{-2} foot candles.

The aviator subjects were seated in the cockpit of a UH-1H helicopter and viewed target pairs (one fixed and one variable) placed at distances ranging from 200 feet to 2000 feet from the helicopter along an inactive runway at Shell Army Airfield, Fort Rucker, Alabama.

The targets consisted of white cloth stretched over metal framework. The larger variable targets were mounted on wheels to allow easier movement. The actual sizes of the targets, as shown in Table 2, were established so that each of the five target pairs would subtend a visual angle of 10' x 30' at their respective testing distances. Lateral angular separation between the two targets of each pair was maintained at 1.5° for all testing distances.

Table 2. Actual Size of the Target Pairs

Testing Distance (Feet)	Target Size (Feet)
200	0.58 x 1.75
500	1.46 x 4.37
1000	2.91 x 8.73
1500	4.37 x 13.09
2000	5.82 x 17.46

Figure 1 shows the resultant thresholds for the three viewing conditions at all testing distances. As with the laboratory study, the measure of threshold was the standard deviation of 10 observations at each distance for all conditions. The average threshold for all six observers is shown in Figure 1. It can be seen that while the monocular and binocular results were similar, the depth discrimination performance with the night vision goggle was clearly inferior at most of the testing distances. Again, Scheffe's S multiple comparison method was used to statistically evaluate these data. Results indicate that there is a statistically significant difference ($p<0.01$) between the unaided daylight monocular and binocular thresholds only at the 2000 feet testing distance. However, NVG performance was significantly different from monocular performance at all distances except 200 feet, and goggle performance was significantly different from binocular performance at all distances except 200 feet and 500 feet.

The results in terms of angular thresholds using the conversion equation discussed earlier are shown in Figure 2. It can be seen, and has been shown previously[7,8,9,10], that the angular threshold for relative depth discrimination decreases with distance. However, these angular thresholds cannot be viewed as stereoscopic disparity thresholds. Clearly, additional monocular cues such as size constancy are operational for these depth discriminations made under field conditions at all of the testing distances.

(3) Modulation Transfer Functions of the Man-NVG System

Using simple clinical measures of visual acuity, it has been determined that Snellen acuity using the goggle is about 20/70, corresponding to a minimum angle of resolution of 3.5 minutes. However, such one-dimensional measures are not completely adequate since angular subtense of the resolution target is the only variable satisfactorily controlled and higher-order factors such as blur interpretation can confound the results. The luminance output and the signal/noise ratio of the goggle do vary with changes in scene luminance. A more quantitative technique to describe man-NVG performance is that offered by the modulation transfer function (MTF) which allows control of such external variables as average scene luminance, contrast, and angular subtense of the resolution target.

The modulation transfer functions obtained in this experiment were determined in the following manner. The subject sat in a darkened room and viewed a television monitor on which was displayed an electronically-generated spatial sine wave grating. The experimenter established and controlled the average luminance on the video display, and the subject controlled the depth of modulation (contrast) of the grating around the average luminance. The subjects were allowed several practice sessions with the equipment prior to the actual data collection periods. Two viewing conditions (unaided and with the NVG) and four average luminance levels were used. The average luminance levels used correspond to the luminance of grass (12% reflection) under a 5%, 25%, and full moon illuminance with no overcast conditions. The fourth level of 25 foot lamberts, considerably above the level with which the NVG would be used, is presented for comparison purposes.

Figure 3 shows the modulation transfer functions at the four average luminance levels for a man wearing the goggle and also when using his unaided vision. The ordinate values of percentage modulation were determined from the relationship,

$\frac{B_{max} - B_{min}}{B_{max} + B_{min}} \times 100$, and are plotted logarithmically as a function of spatial frequency. The data presented in Figure 3 represent the average modulation thresholds obtained from two subjects who were very experienced in making visual psychophysical observations. It can be seen in Figures 3A and 3B that the man-goggle system performs better than unaided vision at the low average luminance levels with a 5% and 25% moon. The depth of modulation (contrast) required to make the grating just visible was less at all spatial frequencies when viewing with the goggle at these levels. However, at a luminance under a full moon (Figure 3C), the observers performed better using unaided vision at high spatial frequencies while performance was better using the goggle at lower frequencies. Figure 3D shows that unaided eye performance is much superior to that achieved with the goggle when the target luminance is sufficiently high to allow the photopic system to operate.

DISCUSSION

Although the MTF's of the man-goggle system have not been published previously, knowledge of the modulation transfer functions of the human visual system[11] and of the

night vision goggle[12] have been available. However, these separate MTF's are insufficient to predict performance of the man-goggle system. Modulation transfer functions do not cascade between optical components which are directly coupled. When the optical components of a system are separated by diffusers, the overall system MTF can be determined simply by multiplying the individual MTF's. However, when the various components are directly coupled, as is the case when a man views with the night vision goggle, the individual MTF's cannot be multipled to determine the overall system MTF. This is because the aberrations of one component may compensate for the aberrations in another and thus produce an image quality for the combination which is superior to that of either component. Any "corrected" optical system utilizes this principle.

As noted previously, Figure 3 shows that the quarter moon performance while wearing the goggle is superior to that of the unaided performance at all frequencies while at full moon light levels, the unaided performance is better at the higher frequencies and is slightly poorer than the man-goggle system at the low frequencies. Therefore, under quarter moon illuminance, the resolution limit of the naked eye is lower than that of the man-goggle system whereas under full moon conditions, the resolution of the goggle is the limiting factor and the naked eye performance overtakes that of the man-goggle system. It should be noted that the amount of light provided by a 5% moon is considered insufficient for NOE flight even with the goggle. One effect of the NVG is to increase the luminance levels of the visual stimulus to a range where the discrimination ($\Delta I/I$) threshold for the visual system is less, and the visual system is more sensitive to contrast. This is shown in its purest form at the lower frequencies where resolution limits do not confound the effect. While the effect of raising the luminance levels into a $\Delta I/I$ range in which the visual system is more sensitive is probably the main influence on the results with the lower frequencies and lower luminances, we cannot eliminate the possibility that the NVG also provides some contrast enhancement or decrement. A nonlinear goggle output brightness in response to a changing scene brightness would provide either contrast enhancement or decrement depending upon whether the shape of the nonlinear curve was positively or negatively accelerated.

Information obtained from the U.S. Army Night Vision Laboratory indicates that the resolution capability of the NVG is 0.67 line pairs/milliradian. However, this limit was established with a microphotometric measurement of goggle output, and scene luminance was not specified. The limit of 0 67 line pairs/milliradian is approximately equal to 12 cycles/degree. Our data using equivalent moon illuminances (Figures 3A, 3B, 3C) show the cut-off spatial frequency to be between 6 cycles/degree and 8 cycles/degree. The actual resolution capability of the man-goggle system is lower than the physical specifications of the goggle, and it is obvious that the contrast detection of the human visual system is less sensitive than the physical system used to specify goggle output.

The present data are in good agreement with our observation that aviators experienced in flying with the night vision goggle prefer to use the goggle at quarter moon illuminance while at full moon illuminance, these same aviators usually prefer to fly with unaided vision. As shown in Figure 3C, resolution with the unaided eye is higher at the full moon illuminance level. It should be remembered, however, that other factors such as the height of the moon may also enter into consideration. For example, if the aviator is flying along a river bed or other partially shaded area and the moon is low in the sky, his immediate surround may be receiving much less illumination than open areas, and he may choose to use the goggle even with a full moon.

The reduced resolution capability with the NVG has probably influenced the results obtained in the depth discrimination experiments. As shown in Table 1, the results obtained with the Howard-Dolman apparatus indicate that the depth discrimination thresholds with unaided binocular vision were superior to those obtained with the remaining three viewing conditions. On a rank order basis, the thresholds with binocular viewing with the night vision goggle were slightly better than unaided monocular viewing thresholds, while thresholds obtained with the NVG and monocular viewing were the poorest. Statistical evaluation indicated that while there was a statistically significant difference ($p<.01$) between the thresholds of binocular viewing and the remaining viewing conditions, there was no significant difference between unaided monocular, binocular-NVG, and monocular-NVG viewing conditions. However, our own observations and comments from every subject used in these

experiments indicate that there is a perceptually significant difference between binocular viewing with the NVG and the two monocular viewing conditions. That is, even though the targets are not as clear, depth judgments using binocular viewing with the NVG are more easily made than those using unaided or aided monocular viewing.

An upright image is achieved with the NVG by means of a fiber optics twist contained within the optics of the tube. The fact that adequate spatial information is retained after the fiber optics twist is shown by the readily fused images presented to the eyes by the two tubes in the NVG. One might reasonably expect disparity information to be retained also. Therefore, the decrement in performance while using the goggle from that of unaided binocular viewing is mainly ascribed to the loss in resolution.

The loss of resolution resulting in larger depth discrimination thresholds can also be seen in a comparison between the unaided and aided monocular performances (Table 1). The Howard-Dolman apparatus is usually considered to yield measures of central stereopsis. Relative depth judgments with this instrument are supposedly based upon disparity of the retinal images of the two eyes. However, cues for depth judgment other than image disparity are available to the observer with the Howard-Dolman apparatus. This is true with the instrument used in the present experiment. One cue, proximal image size, was purposely left available for our subjects. Size was probably the major cue used to make the displacement settings when the targets were viewed monocularly. Although the cues available to the observer when viewing the apparatus monocularly with and without the NVG were the same, the degraded image of the targets with the goggle resulted in a threshold which was much greater than that found with unaided monocular viewing.

The field experiment was designed to measure relative depth discrimination thresholds using the goggle and to compare that performance with depth thresholds of daylight unaided vision. With the preponderance of monocular cues, the cue of retinal image disparity was relatively minor, and little difference between monocular and binocular performance was expected. This supposition was supported as shown in Figure 1 in which the monocular and binocular thresholds are statistically equivalent at all testing distances. However, for distances of 500 feet or greater, Figure 1 also shows that depth discrimination performance with the night

vision goggle is significantly poorer. As with the results of the laboratory study, the larger thresholds obtained while the observers viewed with the NVG are probably the result of the reduced resolution. That is, while information similar to that used by the observers when viewing the targets during daylight was also available to them when they used the night vision goggle, most of the cues, such as texture, gradients, lighting and shading, and linear perspective, had become sufficiently subtle to result in larger thresholds.

Our results have shown that stereopsis, the appreciation of depth by means of the disparity of the retinal images, is significantly reduced when wearing the night vision goggle. Also, when many monocular cues are available, relative depth discrimination is poorer with the NVG for distances of 500 feet or greater. For lesser distances, performance was statistically equivalent to unaided daylight performance. However, it should be noted that our results only reflect accuracy and not other qualitites such as speed or comfort. The relative advantages of stereopsis in aviation are still somewhat equivocal. Two recent reports[13,14] have shown that landing performances of pilots deprived of vision in one eye were as accurate as their landings while using both eyes. However, these reports were based on data obtained in fixed wing aircraft. The visual demands of rotary wing flight might be considerably different. Certainly, military flight profiles involving hovering and flight into and out from unprepared areas without benefit of approach and landing aids might reasonably be expected to place greater demands on an aviator's ability to perceive depth, especially at distances of less than 100 feet. The reduced depth discrimination with the goggle should be recognized so that aviators can be properly trained in preparation for flight with the night vision goggle.

As scientists concerned with the visual welfare of our aviators, we are confronted with a paradox. We have assisted in establishing and have supported high visual standards which our aviators must meet. Now we find that aviators are flying with a viewing device with which few of these requirements are met. For example, a resolution capability of 8 cycles/degree, the full moon illuminance cut-off spatial frequency of the man-goggle system, is approximately equivalent to 20/70 Snellen acuity. We have required that our aviators have normal color vision and a full field of

vision. Yet, the narrowband output of the goggle eliminates color vision, and the goggle offers only a 40° visual field. The present experimental results have demonstrated that depth discrimination is degraded while using the goggle. Obviously, the NVG does not turn night into day nor does it allow a user to operate with daylight photopic efficiency. However, the night vision goggle does provide sufficient visual information to allow flight under ambient light conditions which was not possible with the unaided scotopic vision system. A previous report[1] has shown that use of the goggle allows a lower flight altitude and more accurate hover capability than with unaided vision during periods of reduced illumination levels. A future generation light intensification device should provide more light intensification with improved imagery to further extend the operational effectiveness of aviation support.

SUMMARY

Comparisons of the modulation transfer functions obtained with the man-night vision goggle system and unaided vision show that the performance with the man-goggle system is better when the average target luminances are equivalent to that under 5% and 25% moon illuminance levels. At average target luminance corresponding to a full moon illuminance, performance of the unaided visual system was superior at higher spatial frequencies while the man-goggle system was more sensitive to contrast at the lower frequencies.

Stereopsis thresholds measured with a modified Howard-Dolman apparatus were lower with unaided binocular vision than with the man-goggle system. However, binocular thresholds with the man-goggle system were slightly better than unaided monocular thresholds. Monocular thresholds with the man-goggle system were the largest of any of the four viewing conditions.

Field measures of depth discrimination have shown that relative depth perception with the man-goggle system is inferior to daylight monocular and binocular viewing for distances of 500 feet or greater. For viewing distances less than 500 feet, performance of the man-goggle system was statistically equivalent to unaided viewing.

The following conclusions are supported:

1. The resolution capability of the man-goggle system under full moon illuminance is limited to 8 cycles/degree (approximately equivalent to 20/70 Snellen acuity) or less.

2. Stereopsis, which is based upon retinal image disparity, is degraded with the goggle.

3. Relative depth discrimination with the man-goggle system is statistically equivalent to unaided photopic viewing for intermediate distances, but performance with the man-goggle system is inferior at viewing distances of 500 feet or greater.

4. The AN/PVS-5 night vision goggle does not allow visual performance of daylight efficiency. However, it does provide sufficient visual information to permit rotary wing flight under ambient light conditions which previously prevented flight using only the unaided scotopic visual system.

DISCLAIMER

The findings in this report are not to be construed as an Official Department of the Army position unless so designated by other authorized documents.

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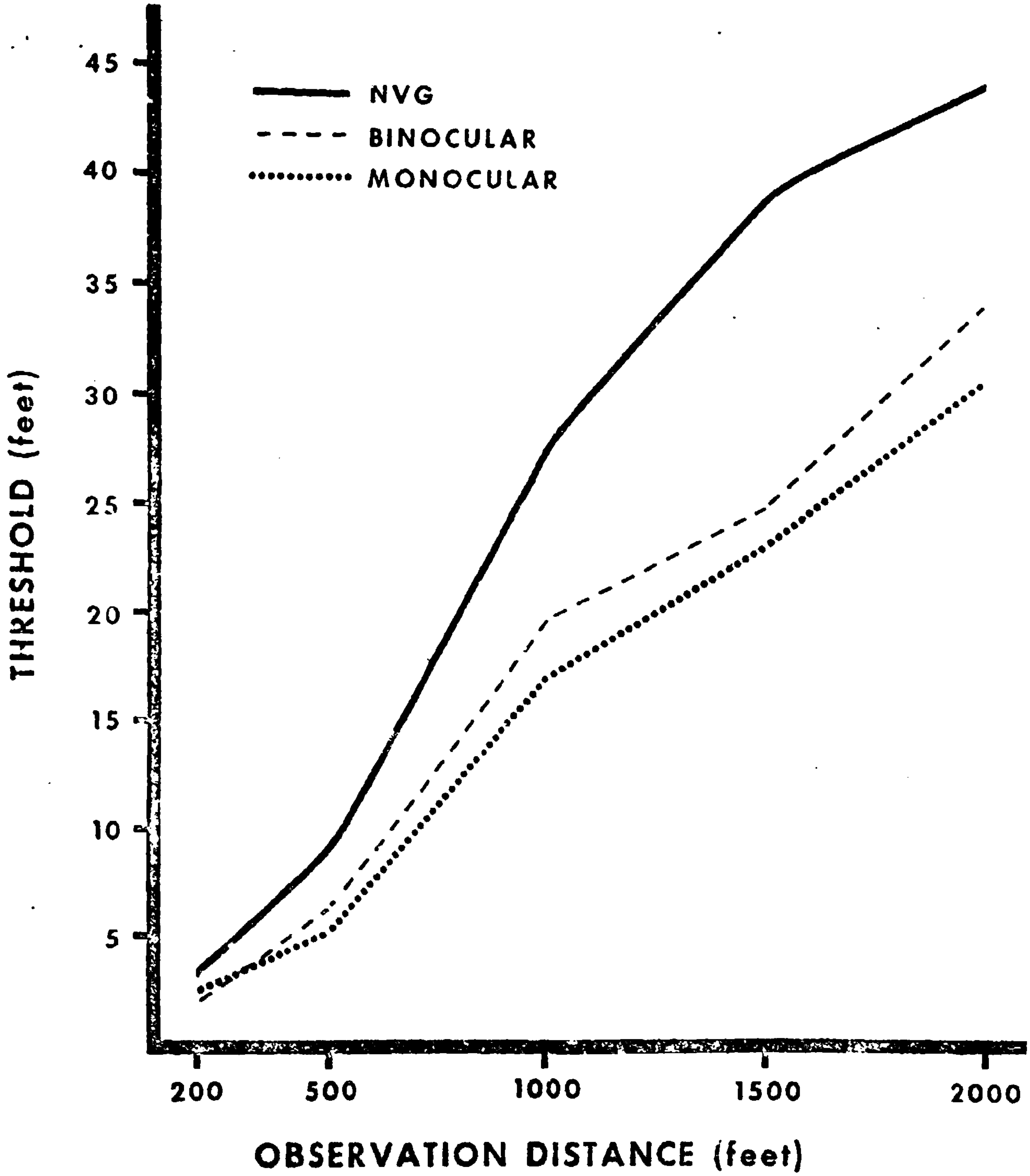


FIGURE 1 LINEAR THRESHOLDS FOR RELATIVE DISTANCE DISCRIMINATION UNDER THREE VIEWING CONDITIONS. DATA POINTS ARE THE AVERAGE FROM SIX OBSERVERS.

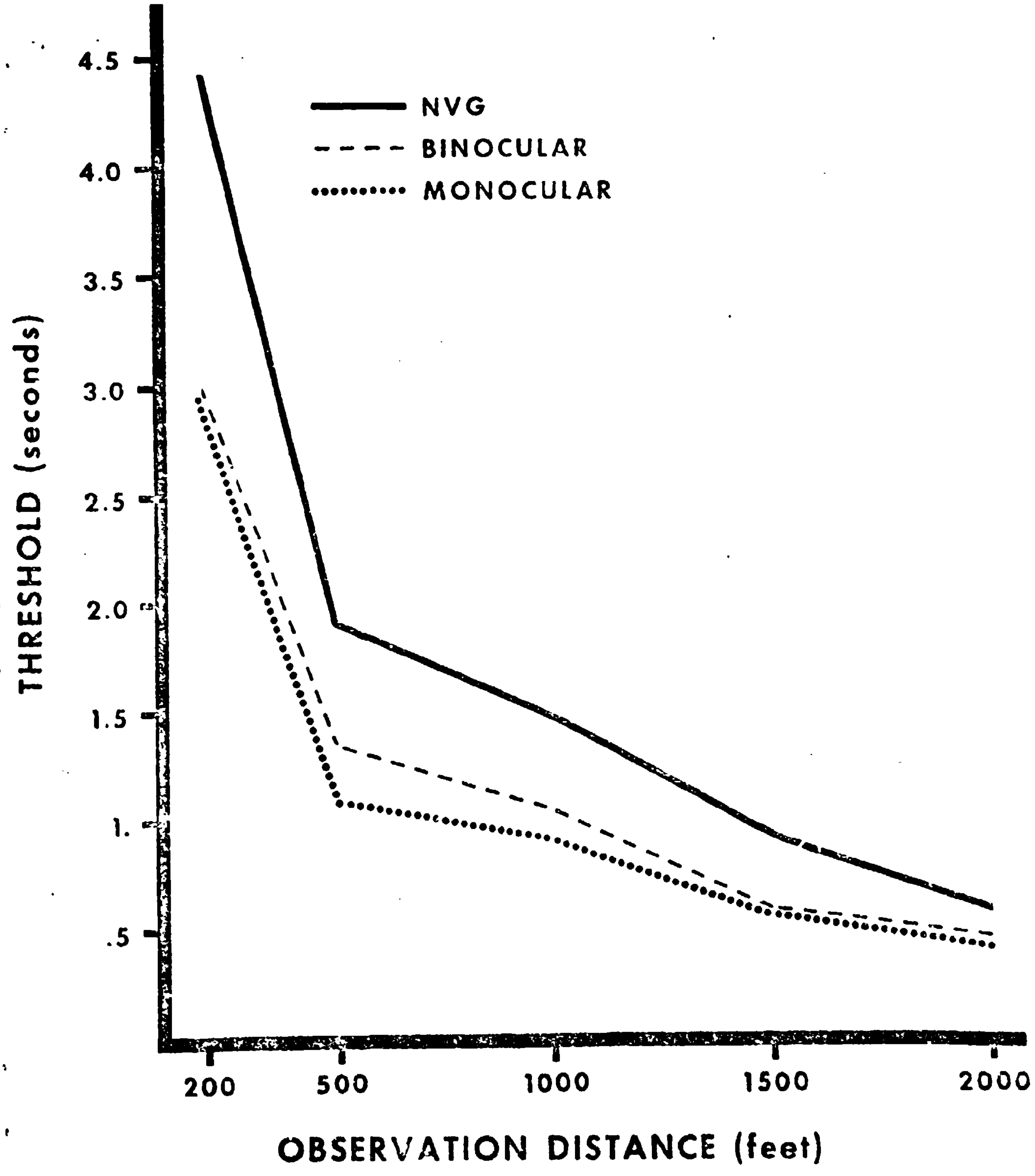
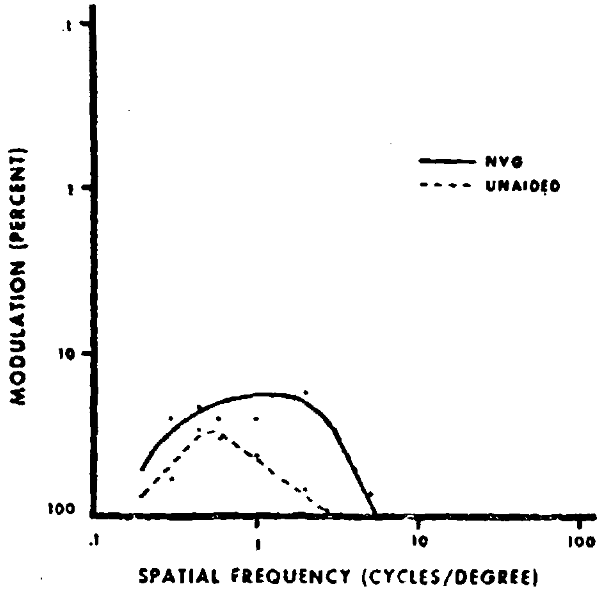
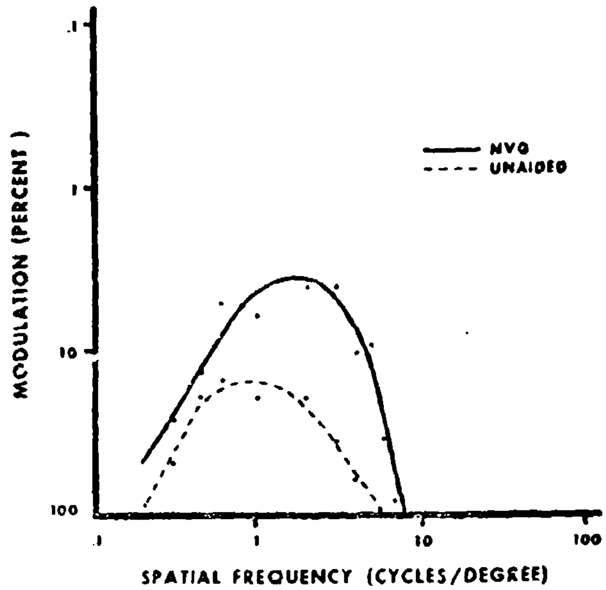


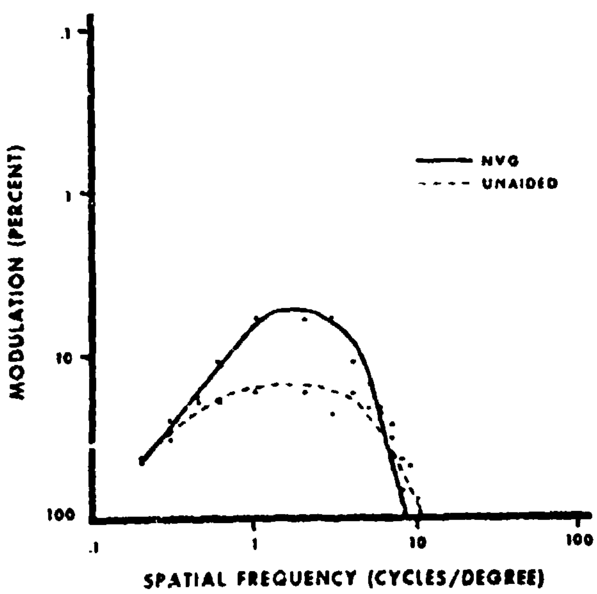
FIGURE 2 ANGULAR THRESHOLDS FOR RELATIVE DISTANCE DISCRIMINATION.



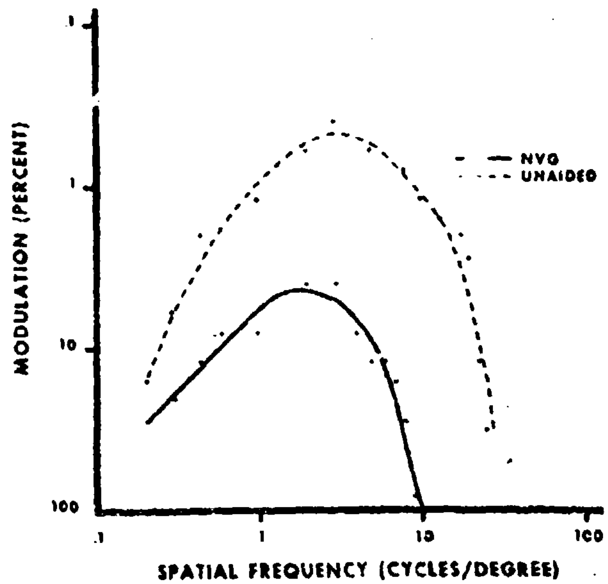
A. AVERAGE LUMINANCE=1.2×10^{-4} Ft-L-(5% MOON)



B AVERAGE LUMINANCE=6×10^{-4} Ft-L- (25% MOON)



C. AVERAGE LUMINANCE=2.4×10^{-3} Ft-L-(100% MOON)



D. AVERAGE LUMINANCE=25 Ft-L

FIGURE 3 MODULATION TRANSFER FUNCTIONS.